

Report on the Program *Continuum Fitting HST QSO Spectra*
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This is the second annual Science/Technical progress report on this project, for the performance period FY2, 3/15/01-3/14/02. This report was due 12/15/01 and we apologize for our delay. We submitted a long and detailed report 12/15/01, beginning "This is a first Science/Technical Progress report for FY2...". Unfortunately we stated that that report was for the same period, FY2:3/15/01-3/14/02, and had a due date of 9/14/01. That report should have been for FY1: 3/15/00 - 3/14/01, due 12/15/00. That report did cover our work in FY1, as was required. It also included our work in FY2 up to the date of submission, 12/15/01, which should have gone into this, the second report. Here we report on our activities, from 12/15/01 to 03/01/02 and we anticipate our work in the coming 2 weeks, through to the end of FY2, 3/14/02, which completes the performance period.

1 Progress Report

The Principal Component Analysis (PCA) method which we are using to fit and describe QSO spectra relies upon the fact that QSO continua are generally very smooth and simple except for emission and absorption lines. To see this we need high signal-to-noise (S/N) spectra of QSOs at low redshift which have relatively few absorption lines in the Lyman- α forest. We need a large number of such spectra to use as the basis set for the PCA analysis which will find the set of principal component spectra which describe the QSO family as a whole. We have found that too few HST spectra have the required S/N and hence we need to supplement them with ground based spectra of QSOs at higher redshift. We have many such spectra and we have been working to make them suitable for this analysis. We have concentrated on this topic since 12/15/01.

1.1 The level of Fluctuations in the Ly α Forest of QSOs

We remove Lyman- α forest and other absorption lines before we use a spectrum in the basis set for the PCA method. At low redshifts $z \simeq 1$ this is relatively simple, but at the redshifts $z \simeq 2 - 3$ this is much harder, in part because there are many lines, but mostly because it is not obvious whether a given fluctuation is Lyman- α forest absorption, emission, or continuum level fluctuations. We do not know of any significant published work on this topic, although we did note (Tytler et al. 1995, in Proc. ESO Workshop, eds. J. Bergeron, G. Meylan & J. Wampler (*Springer: Heidelberg*) 289-298) that in some regions of the Lyman- α forest there appear to be many low column density Lyman- α forest lines which simulate dips in the QSO continuum level. It is now clear that this is an important topic. If fluctuations in the apparent continuum are caused by absorption, or by flux calibration errors, we should remove them before we use a spectrum in the basis set. However, we should not remove them if they come from emission lines or are intrinsic to the QSO continuum.

We have found that many fluctuations in the apparent continuum of a given QSO are erroneous, and come from poor flux calibration. We found this by comparing spectra of a

given QSO which we obtained on different nights with one instrument, and with different instruments. When we flux calibrate these spectra in the usual way, we see differences which are due to inadequacies in the data extraction and flux calibration. We have studied a few QSOs in detail to isolate the following specific problems with the standard data extraction and flux calibration.

1. Sky background. The standard IRAF long slit spectrum extraction algorithm does not perform well when the sky signal varies along the slit. The result is that spectra can have incorrect sky subtraction, which is serious when the QSO is not much brighter than the sky. This typically happens near the UV end of the Lyman- α forest in the spectra which we are using. The spectra then have different slopes at the UV end, depending on the size of the error in the sky subtraction, which is unacceptable for the PCA basis spectra. We solved this problem by writing a more sophisticated long slit extraction program, which works well.

2. QSO spectrum extraction. We have found that the ratio of the flux in two spectra of a QSO from the same instrument, but on different nights varies on scales of hundreds of Ångströms. We traced this erroneous variation to the extraction of the 1D spectra from the CCD image. The proportion of the flux which is extracted depends sensitively on the location of the trace of the 1D spectrum and on the width of the trace. The width of the object spectrum varies along the spectrum because the focus varies, and the amount of flux in a fixed number of pixels varies because the spectrum is not exactly aligned with the CCD rows. The solution is to spend more time inspecting and adjusting the trace, and to extract the flux from more sky area, which decreases the S/N. We have found that 7 spectra of one QSO extracted in this way showed no significant differences on the scale of hundreds of Ångströms. We may implement an optimal extraction algorithm to give better and faster results.

3. Large scale flux variations. We have found that spectra which seem very similar on small scales of hundreds of Ångströms may still differ significantly on scales of thousands of Ångströms. We do not know the cause of these differences. For now we have decided to ignore these large scale trends because they will simulate slight changes in the overall continuum slope, which are probably readily accommodated by the PCA method.

4. UV wavelengths. UV wavelengths are important because we would like the PCA basis vectors to cover down to the Lyman limit in QSO spectra, and we must observe QSOs at the lowest redshifts accessible from the ground to minimize the amount of Ly α absorption. Our usual flux calibration method is completely inadequate at wavelengths < 3300 Å where there is strong absorption in the atmosphere. We are now trying two ways of fixing this. First, we can treat the absorption as a part of the instrumental response function, and directly divide it from the QSO spectrum. This will not work if the absorption varies with air mass and the QSO and star were observed at different air mass. In that case we use "B-star" routines which measure the absorption in the spectrum of the standard star, and scale it by air mass before removing it from the QSO spectrum.

5. Flux standards. We have found that the fluxes which are usually used for standard stars, those from Oke (1990) have erroneous fluctuations in the 4% range which are often larger than our S/N. We have found that HST STIS spectra are available for most flux standard stars, and these have both insignificant erroneous fluctuations and much higher spectral resolution. Spectra which we have calibrated using these STIS spectra appear to be much more reliable than those calibrated using the Oke fluxes.

1.2 Origin of the fluctuations

There remain significant 5% fluctuations in the Lyman- α forest region of QSO spectra which we believe are real and not artifacts of the data reduction. While some of these may be on the sides of weak emission lines, others are far from the wavelengths of suspected emission lines. We will use high resolution spectra to help decide whether these variations are caused by absorption, in which case we should try to remove them from the spectra used for the PCA.

1.3 Plan

Our first task is to develop a pipeline to use what we have learnt and allow us to rapidly reduce hundreds of spectra which we need for the PCA. This will implement tools to deal with the issues mentioned above.

We will use these spectra to look for weak emission lines in the Lyman- α forest.

We will then need to explore how we can rapidly remove Lyman- α forest and other absorption from these spectra. The manual methods which we used with the $z \simeq 1$ HST spectra are impractical and will not work well.

Concurrently, we will use existing high resolution spectra to determine whether the 5% fluctuations in the Lyman- α forest are caused by Ly α absorption.

These steps should give us enough QSO spectra to make the PCA method work, and allow us to complete this project.